AE 451A

EXPERIMENTS IN AEROSPACE ENGINEERING - II

PERFORMANCE ANALYSIS OF A TURBOJET ENGINE

LIST OF SYMBOLS:

Symbol	Meaning	SI Units		Symbol	Meaning	SI Units
C_p	Specific Heat at constant Pressure	J/(kg/K)		P_0	Total Pressure	Pascal
F	Thrust	Newton		T_0	Total temperature	Kelvin
Ma	Mach Number	-		T	Static Temperature	Kelvin
m_a	air mass flow rate	kg/s		γ	Ratio of Specific Heats	-
m_f	fuel mass flow rate	kg/s		ρ	Density	kg/m^3

OBJECTIVE:

The objective is to understand the operation and evaluate the performance of a turbojet engine, at different operating conditions.

DESCRIPTION OF THE EXPERIMENT:

The ambient air is drawn in, and is first brought to a higher pressure in the single-stage radial compressor. In the downstream combustion chamber, fuel is added to the compressed air and the resulting mixture is combusted. The temperature and flow velocity of the gas increases. The gas flows out of the combustion chamber into the single-stage axial turbine and discharges a portion of its energy to the turbine. This turbine drives the compressor. In the propelling nozzle, the partially expanded and cooled gas expands to ambient atmospheric pressure and the gas accelerates to high speeds.

The high-speed gas outflow generates the thrust. In order to reduce the outlet temperature, the exhaust gas stream is mixed with the ambient air in a mixing pipe. The gas turbine is started fully automatically with the aid of an electric starter. Between the compressor and the turbine is the annular combustion chamber. The movable platform, with a force sensor, enables measurement of the thrust.

The speed, temperatures, static pressures and mass flow rates of the air and fuel are recorded using appropriate sensors. The measured values can be read on digital displays.

CHECKLIST BEFORE STARTING:

1. Check fuel lines for air bubbles or blockages.
2. Check that fuel tank vent is unobstructed
3. Make sure there is sufficient fuel for a complete test run.
4. Set throttle trim and turbine (Aux channel) mode switch to OFF
5. Lift the turbine desk at the front end to enable residual fuel on turbine to come out.

PROCEDURE:

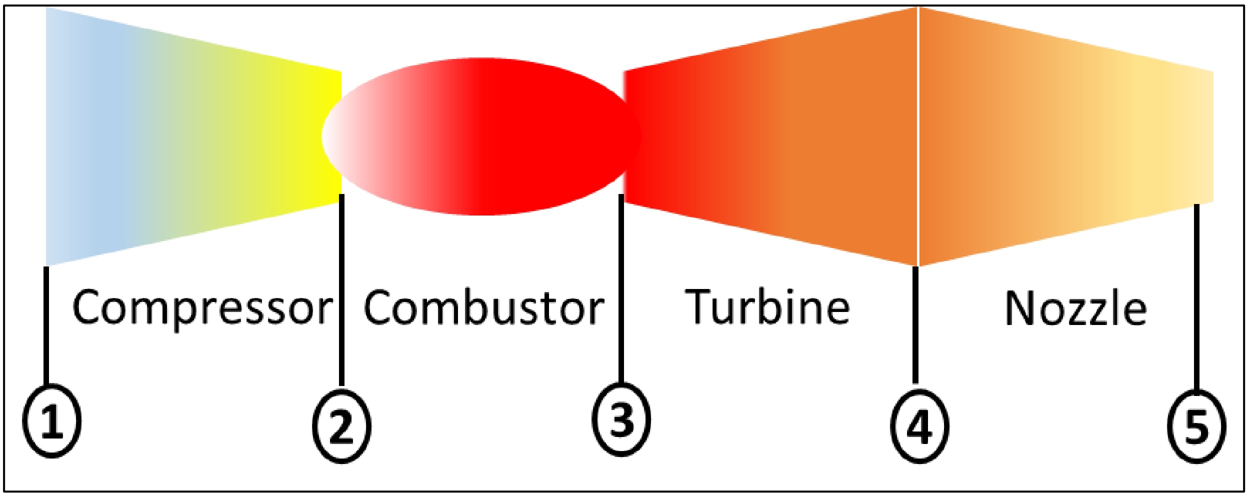
1. Set the throttle trim switch to ON and set throttle lever to IDLE (minimum).
2. Switch on the ET796 at the master switch and set turbine (Aux channel) to RUN.
3. The 3 LED lights will light up in sequence. Start the automatic starting process by fully opening the throttle lever.
4. The starter motor brings the turbine to starting speed. The glow plug is activated and auxiliary fuel is given for ignition. Ignition is identified by a rise in temperatures seen on the display panel.
5. After a short time, bring the throttle to IDLE position and being the experiment.
6. Slowly vary the rpm of the engine from 40,000 to 100,000, in steps of 10,000 rpm.
7. At each step, record all the parameters displayed in the digital display panel. After reaching 100,000 rpm and recording all the required data the experiment is complete.
8. After completing the experiment, turn off the turbine (Aux channel) mode switch to AUTO OFF. To cool the turbine, the starter motor continues running until a temperature of below 100 ^oC is reached. Once the turbine has cooled down, switch the turbine (Aux channel) mode switch to OFF.

PRECAUTIONS:

1. Do not operate unless a lab technician or teaching assistant is present.
2. NEVER exceed the maximum RPM limit of 110,000 RPM.
3. While increasing RPM, do so slowly, in the stipulated increments only.
4. During the experiment, the gas turbine components will get very hot. Do not touch any part of the gas turbine during the experiment.
5. Stay well away from the exhaust of the gas turbine during operation.

CALCULATION PROCEDURE:

Block diagram with station numbering is given below.



Station 1 - Ambient conditions and Compressor Inlet
Station 2 - Compressor exit and Combustor Inlet
Station 3 - Combustor exit and Turbine Inlet
Station 4 - Turbine Exit and Nozzle Inlet
Station 5 - Nozzle Exit

1. **Units Conversion and other assumptions:**

$$m_a\left(\frac{kg}{s}\right) = \frac{m_a\left(\frac{Ltr}{s}\right)\times\rho_{ambient}}{1000} \text{--} (1)$$

$$m_f\left(\frac{kg}{s}\right) = \frac{m_f\left(\frac{Ltr}{hr}\right)\times\rho_{fuel}}{3600\times1000} \text{--} (2)$$

Where, $\rho_{air} = 1.2\ kg/m^3$ and $\rho_{fuel} = 840\ kg/m^3$

Temperature (K) = Temperature (°C) + 273

Pressure (kPa) = Pressure (bar) $\times$ 100

$\gamma_{cold} = 1.4$ and $\gamma_{hot} = 1.33$

$C_P(cold) = 1005\ (\frac{J}{kg.K})$ and $C_P(hot) = 1150\ (\frac{J}{kg.K})$

2. **Ambient Conditions:**
   Pressure (P_{01}) = measured from barometer in lab or assume 101.325 kPa
   Temperature (T_{01}) (K) = measured from thermometer in lab

3. **Compressor Pressure Ratio (P_{02}/P_{01}):**
   Compressor Exit Pressure (P_{02}) (kPa) = P_{01} + [P_{02} (bar) $\times$ 100]
   Since the measured value is gauge pressure, we add ambient pressure to get absolute pressure. Also, convert from bar to kPa by multiplying 100.

Knowing P_{02} and P_{01} (P_{01} is the same as $P_{ambient}$), we can now estimate the compressor pressure ratio, P_{02}/P_{01}.

Combustor Exit Pressure (P_{03}) (kPa) = $P_{02} \times 0.95$
Assuming that there is a 5% pressure loss in the combustor, we can estimate combustor exit pressure from the compressor exit pressure.

4. **Compressor Efficiency (η_c):**

$$\eta_c = \left(\frac{\left(\frac{P_{02}}{P_{01}}\right)^{\frac{\gamma-1}{\gamma}} - 1}{\frac{T_{02}}{T_{01}} - 1} \right)$$

5. **Global Equivalence ratio (ϕ_g):**

$$\text{Global Equivalence Ratio} = \frac{Actual\ (\frac{Fuel}{Air})}{Stoichiometric\ (\frac{Fuel}{Air})}$$

Actual $(\frac{Fuel}{Air}) = \frac{m_f}{m_a}$ and
Stoichiometric air to fuel ratio is 15 for ATF. It can be calculated using the stoichiometric equation for the combustion of ATF (use $C_{12}H_{26}$ to simulate ATF composition).

6. **Specific Thrust:**

$$Specific\ Thrust = \frac{Thrust\ (Newtons)}{Total\ Intake\ Air\ Flow\ (\frac{kg}{s})}$$

7. **Thrust Specific Fuel Consumption (TSFC):**

$$TSFC = \frac{Fuel\ Consumption\ (\frac{kg}{s})}{Thrust\ (Newtons)}$$

RESULTS AND DISCUSSIONS:

1. Convert parameters to standard units and record in a tabulated form.
2. Calculate and plot the compressor pressure ratio, compressor efficiency, specific thrust, thrust specific fuel consumption (TSFC) and global equivalence ratio w.r.t. different RPMs.
3. Plot all the measured temperatures w.r.t RPMs and discuss the trend.
4. Calculate the exit Mach number from the current data.

REFERENCES

1. Elements of Gas Turbine Propulsion by Jack D. Mattingly.
2. Gas Turbine Theory by Saravanamuttoo.